Treichel C, Strohbach BJ, Carr S, Loots S & Neckel A (2021) *Euryops walterorum*, a declining restricted-range endemic of the Greater Gamsberg. *Namibian Journal of Environment* 5 A: 25-38.

APPENDIX 1: A PROPOSED LONG-TERM MONITORING PROGRAMME OF THE *EURYOPS WALTERORUM* POPULATION

The need for monitoring

The possible effects of climate change as well as the impacts of infrastructure developments are expected to result in a continuing decline of this population, leading to a detrimental effect on the population's viability with extinction in the wild as a possible outcome in the foreseeable future. As there are no empirical data confirming any of the trends observed in the population on the plateau, a long-term monitoring initiative has been initiated by a consortium consisting of the National Botanical Research Institute (Ministry of Environment, Forestry and Tourism), the Biodiversity Research Centre of the Namibia University of Science and Technology, as well as independent lay botanists with a special interest in the project. This initiative is endorsed by the Max Planck Society as the landowners.

The aims of this initiative are:

- to establish a baseline data set on the present-day population
- to establish a monitoring system to monitor the population dynamics in relation to climatic trends and anthropogenic impacts
- to establish a conservation strategy for *E. walterorum*, both *in situ* and *ex situ*.
- to determine inter-population genetic relationships (one population or two populations on the northern and southern side of the plateau?)
- to determine phylogenetic relationships with other species of the genus *Euryops*

Monitoring plot layout

In preparation of the baseline survey, as well as setting up a monitoring scheme, a map of habitats on the plateau was created through visual interpretation of Google Earth and Microsoft Bing Aerial images at high resolution (Figure 1). Three natural habitats were identified, being shrubland (i.e. likely *E. walterorum* habitat), grassland and eroded edges. In addition, around the telecommunication tower and at the astronomy station, areas of anthropogenic influence were identified.

The BIOTA-Africa project established a scheme of setting up long-term biodiversity observatories (Jürgens *et al*. 2010a, 2012). In principle, a square km (1 000 x 1 000 m) area is selected and subdivided into 100 one-hectare blocks. Each of these blocks is numbered according to a row/column scheme, starting in the north-western corner, and characterised according to their habitat. With this information, the one-hectare blocks are randomly ranked, using the d'Hondt divisor method so that various habitat types are equally selected (Jürgens *et al*. 2010a, 2012). (The d'Hondt divisor method is a randomisation procedure, taking data categories into consideration. Each category (in this case, habitat) has thus an equal chance to be high-ranked in a randomised ranking procedure). This subdivision and ranking scheme was adopted for the monitoring scheme on the plateau of the Greater Gamsberg for the following reasons: (a) it takes all habitats into account. We can thus monitor the vegetation in all habitats, thus allowing the observation of various eventualities, e.g. if the population encroaches into the central grassland, or the eroded edges expand and the population of *E. walterorum* slowly recedes. (b) The random ranking scheme provides a way to preselect plots in an unbiased way, allowing statistically valid comparisons without the need to tediously survey every single hectare on the plateau. (c) By adopting this scheme, the Gamsberg can be compared to other similar biodiversity observatories (Jürgens *et al*. 2010a, 2012) (see also http://www.sasscalobservationnet.org/).

In order to use this principle of plot selection for long-term monitoring, a 100 x 100 m cell grid was placed over a Microsoft Bing image of the Gamsberg plateau, starting at Universal Transverse Mercator (UTM) coordinates x 623988.957 and y 7418927.285 (zone UTM 33s). As a regular 1 km^2 would not have fitted on the plateau, extending onto the steep sides of the mountain, and would not have covered both northern and southern populations of *E. walterorum*, it was decided to extend this grid over the entire plateau, but limited to only the plateau. This resulted in a grid consisting of 23 columns and 20 rows, subdividing the plateau into 217 one-hectare blocks (Figure 2). The blocks were subsequently numbered, adapting the basic numbering scheme of a regular biodiversity observatory as follows: The north-western most hectare (off the plateau) would still be 00, the north-eastern hectare (also off the plateau) would be 023. In the northern-most row only hectare-blocks 014, 015, 016

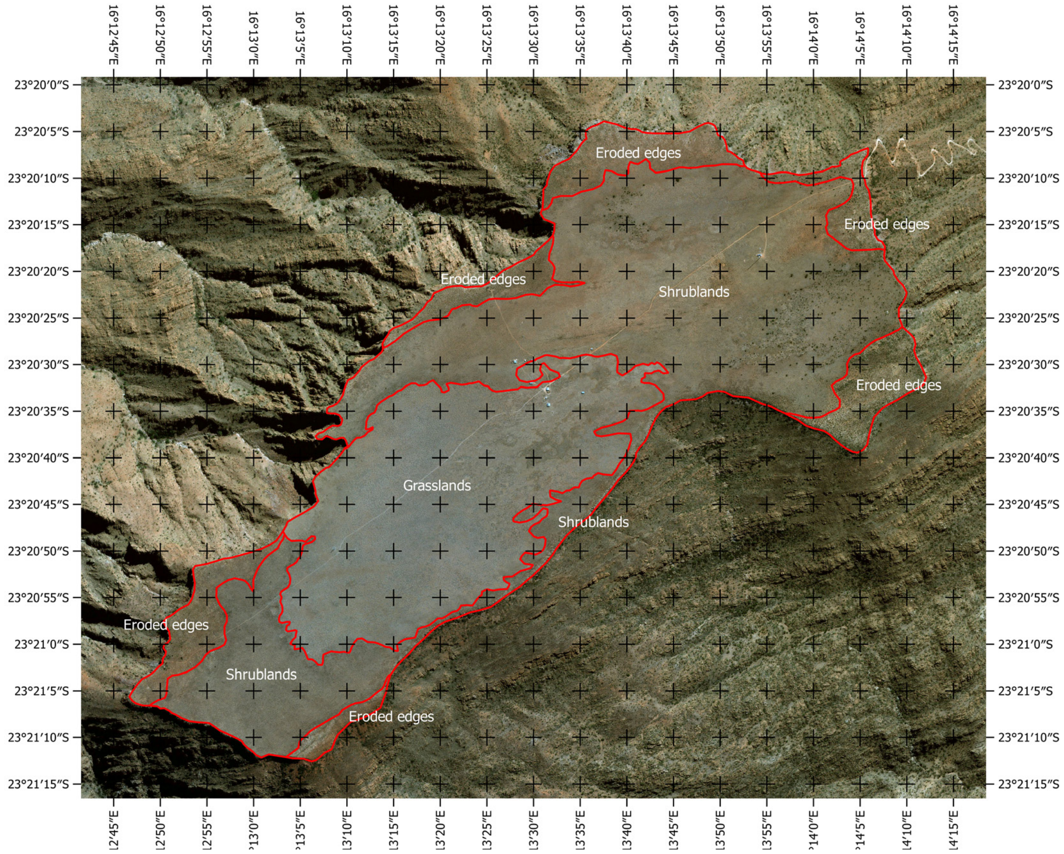


Figure 1: *Habitats identified and delineated on the Gamsberg plateau, using Google Earth and Microsoft Bing imagery. The shrublands represent likely* Euryops walterorum *habitat*

and 017 are considered, being on the plateau. This numbering system would continue, with the next row starting at 100 and ending at 123, whilst the last row would start in the south-western corner with 2000 and end with 2023 (Figure 2). Also in this row, only hectare blocks 2003, 2004 and 2005 are actually considered along the southern edge of the plateau. Stratification of these one-hectare blocks was done based on the habitat map in Figure 1, adding a 4th category "Infrastructure" for the communications tower and the astronomy station (Figure 2b). Based on this categorisation, the ranking, using the d'Hondt devisor method, was conducted to pre-select the permanent sample plots (Figure 2a). Initially, the top 40 randomly ranked hectares across the plateau were selected for surveying and monitoring. These plots covered all habitats, allowing the monitoring of all phytodiversity on the plateau. This way, positive or negative population shifts of *E. walterorum* can be monitored. A listing of all hectare blocks, their mid-point co-ordinates, assigned dominant habitat types and ranking is provided in online Appendix 2.

The actual survey plot positioning and layout also follows the scheme used for the biodiversity observatories: The centre of the hectare has been pre-calculated based on the hectare's UTM position. A 10 x 10 m survey plot was positioned to the north of the centre, strictly arranged according to the cardinal directions (i.e. north-south and east-west) (Figure 3). Unlike the regular biodiversity observatories, only a 10 x 10 m plot was used, not the full 20 x 50 m plot. The reason is the structure of the vegetation: being a low shrubland, a relatively small survey plot is sufficient to capture the diversity (Brown *et al*. 2013).

Initial survey

During an initial field visit in November 2019, 18 of the 40 top-ranked plots were marked out and surveyed. The on-site plot position was determined with a hand-held GPS receiver. The centre was permanently marked with a 60 cm long, white-ended steel dropper. This centre was used to set out the baseline of the 10 x 10 m plot, to the north of the hectare centre (Figure 3). The four corners of the plot were marked with hidden tent pegs. Plots within the anthropogenic influence zones were marked with tent pegs only (including the centre marker). The centre position was determined using a hand-held GPS, whilst the outer corners were measured with measuring tapes and GPS positions. Simultaneously with the marking, a basic survey of each marked 10 x 10 m plot was made.

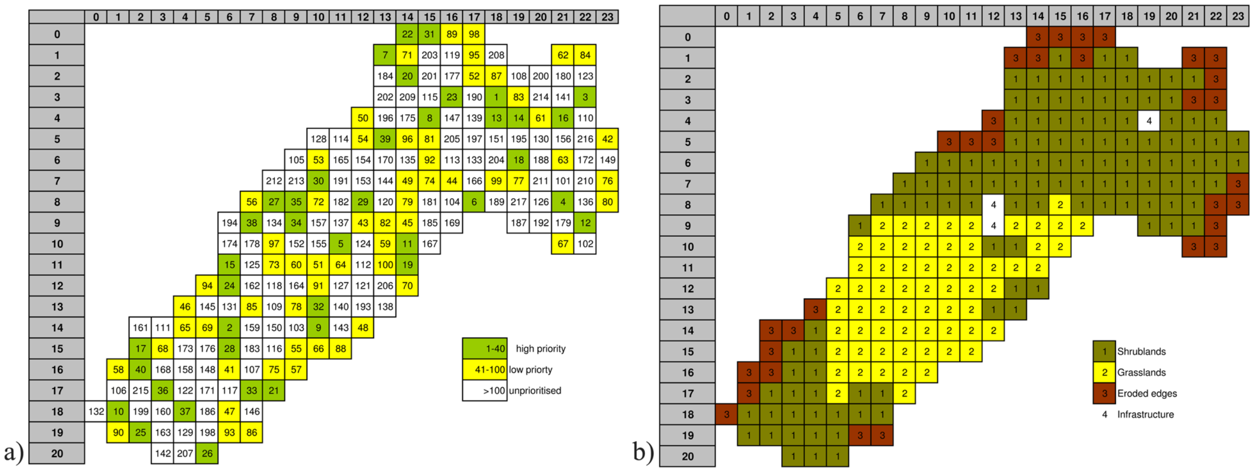


Figure 2: *Ranking scheme of the one-hectare blocks on the Gamsberg plateau. The ranking scheme follows the random ranking scheme as applied to the long-term biodiversity observatories. (a) (left) Ranking of the one-hectare blocks, (b) (right) Categorisation of dominant habitat types*

These data included the number of live and dead *E. walterorum*, as well as their size distribution. Furthermore, their relative position on the plot was also noted, thus allowing for the monitoring of individuals. The survey was completed with a series of photographs from the centre point across the entire plot, allowing for further fix-point photography comparisons of the population (Figure 4a).

To complement the baseline survey, an aerial survey was conducted using a multi-rotor drone, taking ultra-high resolution images (< 1 cm ground resolution) at low altitude (16 m above surface) of the 10 x 10 m survey plots (Figure 4b). These images will assist in the monitoring of individual plants on these plots over time. Although individual plants are distinguishable on the aerial images, a way still needs to be devised to discriminate between various species. Both *Euryops walterorum* and *Eriocephalus dinteri* have a similar dwarf shrub-like habit. As a first step, a sketch map of plants observed in each plot is drawn during surveying.

As an additional measure, 70 individual *E. walterorum*, distributed over the whole plateau, some of them inside the surveyed plots, were tagged with a numbered label (Figure 5), their location was determined by GPS, and they were measured and photographed to get more information about height, condition, flowering and seed production.

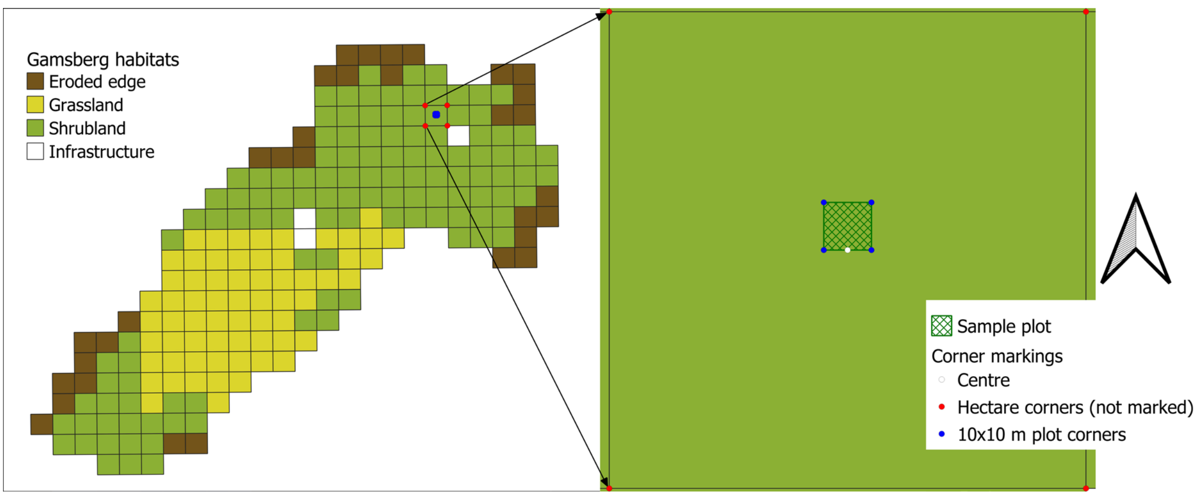
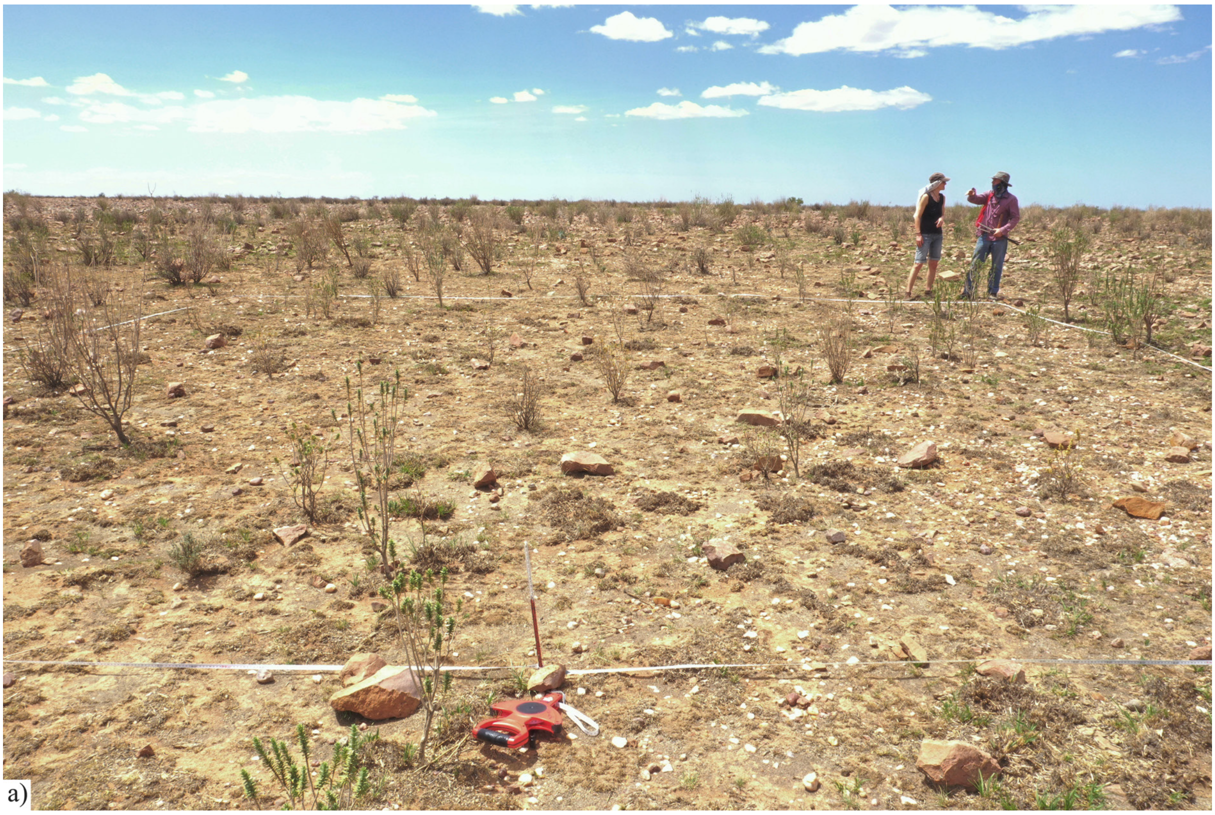


Figure 3*: Schematic view of the plot layout within a single hectare block, following the sampling scheme utilised on the biodiversity observatories.*



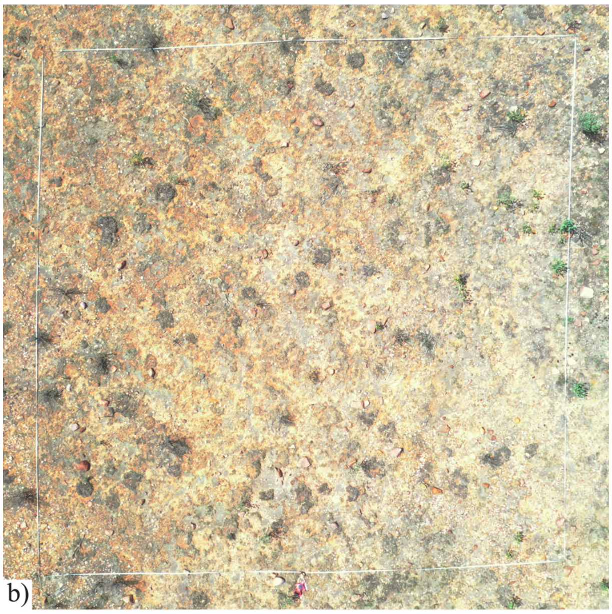


Figure 4: *Photographs of plot 318 (rank 1), January 2020. (a) (top): The 10 x 10 m plots were photographed in full from eye level from just south of the centre peg towards the north; and (b) (bottom) from the air using a multi-rotor drone.*

A basic descriptive analysis was done with the collected data and displayed in a geographical information system (GIS) map (Figure 6). *Euryops walterorum* is restricted to the shrublands along the northern, eastern and southern parts of the plateau (about 110 ha), with none occurring in the central grassland, nor along the boulder-strewn eroded edges of the plateau. Within the shrublands, the stands are unevenly distributed. It was evident that the population on the northern and eastern part of the plateau showed a larger amount of live plants than on the southern part of the plateau. This is possibly due to the fire which occurred in 2016 on the southern part of the plateau (see Figure 12 in main text), but could also have resulted from uneven rainfall distribution over the plateau.

In a few plots, over 50 individual plants were counted, but most plots had about two plants or less, and many had none (Figure 7). This is in stark contrast to previous observations, which showed a far denser and far more vigorous population (see Figures 8 and 10 in main text). Most plants were between 50 and 100 cm high. From the current plot data, the estimated total number of mature plants on the plateau was calculated to be about 22 000.

***Figure 5:** Seventy* Euryops walterorum *plants were tagged with a numbered label for future identification and measuring; here the one with label number 17.*

Refinements to the monitoring scheme

The monitoring system is designed to measure the long-term trends in the population parameters and the subsequent need for mitigation measures to ensure the survival of the species. It will help to identify the possible reasons for the observed decline and provide an indication of whether the population decline is a steady, continuous process or the result of severe reduction events, like those observed in 1983 and 2017 (Giess 1984, personal observations).

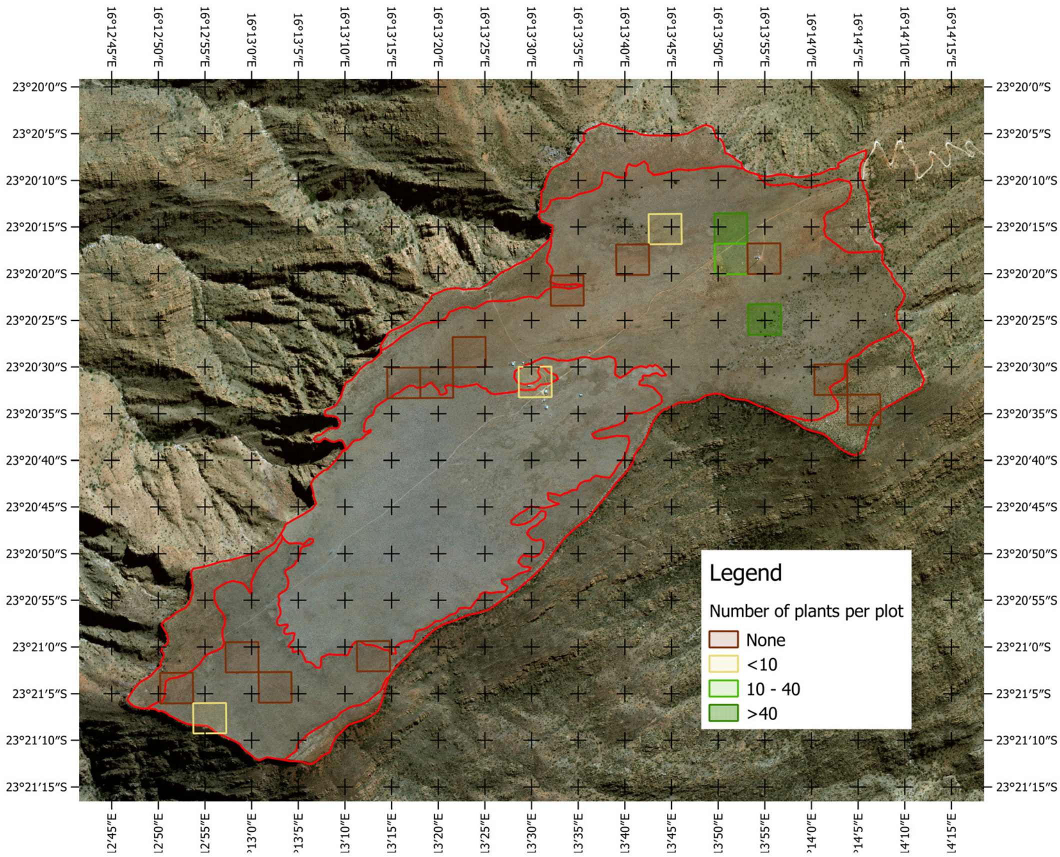


***Figure 6**: Surveyed densities of the* Euryops walterorum *population.*

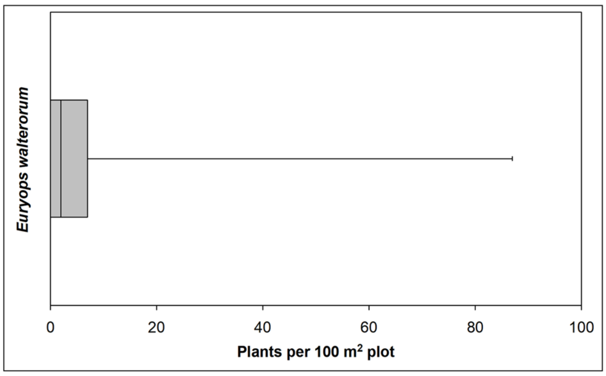


Figure 7: *Density distribution of* Euryops walterorum *found in the initial sample plots. Note the skewed distribution, with the median at two plants per plot, which translates to 200 plants per hectare, or a total population of about 22 000 plants.*

Due to the species' uneven distribution, even within its typical habitat, it was realised that the top 40 priority plots, of which 19 were within the shrubland, would not be a sufficiently large sample to monitor the population of this restricted-range endemic. Therefore it was decided to include in the permanent monitoring scheme the hectares ranked 41 to 100 within the shrubland habitat, amounting to an additional 25 plots (Figure 8). It is important to note that these additional plots are part of the original randomised ranking scheme and were not subjectively selected. These plots and the as yet unmarked plots ranked between 1 and 40 are to be marked during the next visit to the plateau.

Consideration is given to include the plateau in the long-term biodiversity monitoring network in Namibia as an Auxiliary Observatory (SASSCAL 2020). In conjunction, an automated weather station on the plateau is planned, to provide more reliable data about climatic conditions for verifying the impact of the climatic change on the species. Since the uneven density of the *E. walterorum* population, both on the northern and southern side of the plateau, might be the result of uneven rainfall distribution over the plateau, the installation of several automatic rain gauges on various plateau sites for verification is being discussed.

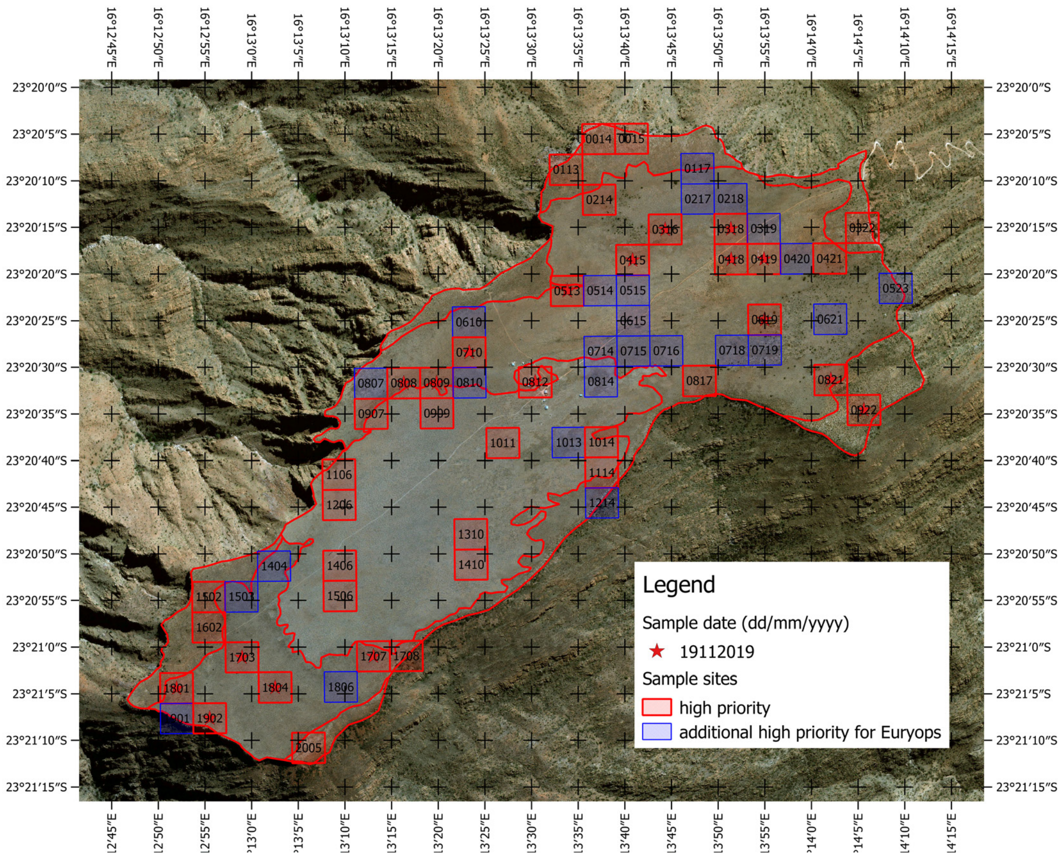


Figure 8*: Monitoring plot selection on the Gamsberg plateau. The high priority sites indicated in red are the top 40 ranked plots, whilst the additional high priority plots for* Euryops walterorum *(indicated in blue) are shrubland habitat plots ranked between 41 and 100.*

In addition to the survey of the *E. walterorum* population, a complete floristic survey, including plots on non-*E. walterorum* habitats, for the purpose of vegetation description and long-term biodiversity monitoring is planned. This is in line with the survey standards applied at the biodiversity observatories (Jürgens *et al*. 2010b) and can also contribute to the Phytosociological Database of Namibia (Strohbach 2001, Strohbach & Kangombe 2012). This is to be augmented by more detailed habitat studies, specifically the elevation profile of the plateau and structure of the rocky underground would clarify whether parts of the remaining population are located in potential seasonal wetlands like rainwater-storing depressions or subterranean water reservoirs and help to explain why *E. walterorum* does not grow in the central grassland.

Phylogenetics

In order to establish phylogenetic relationships between the subpopulations, as well as to other related *Euryops* species, three voucher specimens and a number of DNA samples were collected from *E. walterorum* plants at different points on the plateau. Vouchers were requested by the National Herbarium of Namibia. The DNA analysis may lead to interesting insights into the species and population, for example any south/north differences, as well as providing a clearer picture of the relationship between this isolated species and other *Euryops* species found further south in Namibia and South Africa (cf. Devos et al. 2010). This work will continue in parallel to the survey and long-term monitoring, and may feed into conservation strategies in future.

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